NASA SPACE OPERATIONS SYSTEM*

Richard P. Mathison
Chief Engineer
Telecommunications and Mission operations Directorate
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Abstract

The international and national environment for the conduct of space missions has been changing significantly over the last several years. The changes require that the NASA Space operations System substantially increase its productivity and reduce the cost of providing space operations services. The NASA Space operation System consists of all the functions, services, tools, physical elements, and people that NASA uses to do space mission operations. The designers of the System of today optimized the performance for individual missions in the deep space, human exploration, near Earth, and suborbital mission domains. Consequently, there is significant duplication of functions and insufficient interoperability among the networks and mission control centers in the System, Meeting the challenge requires that the System provide data acquisition, space vehicle control, mission operation services, and products with the same ease and reliability as acquiring services and products from a public utility. It should be essentially invisible to the user and the user should get reliable service with minimal knowledge about the details of the System. The System should be scaleable. It should adapt to match the capacity and performance requirements of future missions. Appropriate elements of the System should interconnect functionally (not just physically networked) to provide customers a single standardized interface for services such as telemetry or metric tracking. This single service interface is the interface to request services and the interface for data as a result of service execution. This paper describes these characteristics that the NASA Space Operations System should have by about 2010.

Introduction

The international and national environment for the conduct of space missions has been changing significantly over the last severat years. The changes require that the NASA substantially increase the productivity and reduce the cost of doing space mission operations. This paper discusses the principles and characteristics that the NASA Space Operation System should exhibit to meet the challenge by the 2010 era. The base for these ideas is an understanding of the requirements that designers of future missions are beginning to place on space operations.

The NASA Space Operation System consists of all the functions, services, tools, physical elements, and people that NASA uses to do space mission operations. NASA mission operations are in four domains, deep space, human exploration, near Earth, and suborbital. The principal assets of the System, Table 1, that the Space Operations Management Office manages, provide the services and toots to these mission domains.

These include services and elements owned by the government and services and elements purchased from industry. The interfaces include spacecraft to ground, spacecraft to Space Network, networks to payload-operation-centers, payload-operations-centers to mission service interfaces, and the interfaces among mission service elements.

The paper first describes the environment for space operations, gives brief remarks about the design of the current System, and states the future vision. Then it discusses 8 principles and characteristics that the System should exhibit. It does not describe specific system designs or system concepts as such.

Many individuals contributed to the ideas reported herein. The most significant are R. Burt, J. C. Klose, P. Shames, and W. Tai.

Asset	NASA Center
Advanced Multimission Operations System (AMMOS)	JPL
Countdown and Launch Checkout System (CLCS)	KSC
Deep Space Network (DSN)	JPL
Flight Dynamics Facility (FDF)	GSFC
Huntsville Operations Support Center (HOSC)	MSFC
Integrated Planning System (IPS)	JSC
Low Earth Orbiter Network (LEON)	GSFC
Mission Control Center (MCC)	JSC
Mission Operations Centers (MOCs)	GSFC
NASA Integrated Services Network (NISN)	MSFC
Remote Extension Moscow (REM)	JSC
Science Data Processing Facility (SDPF)	GSFC

Table 1 NASA Space Mission Assets

The Environment

International

Today a global economic contest has replaced the Cold War as the motivating force behind national investments. Success in this situation requires prestige, technology, and efficient production. These are achieved by doing hard-to-do, never-done-before kinds of things, and doing them within stated costs. Because space exploration enhances national prestige and drives technology, it continues to be on the nation's investment agenda.

The present cost constrained environment has encouraged international partnerships. These range from the development of the International Space Station to the operation of instruments on automatic spacecraft. These partnerships tend to form during the early phases of mission development, and significantly influence the design and cost of mission operations. Expect the extent of international partnering to increase in the future.

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National Space Policy[1]

A recent comprehensive review of the National Space Policy resulted in a significant update to the policy. The revised policy comes at a particularly exciting and challenging time for the U. S. Space program. The International Space Station moved from drawing board to hardware production. NASA initiated a new program to develop the next generation reusable launch system. DoD, NASA, and NOAA established an Integrated Program Office that is responsible for the design, acquisition, and implementation of the future National Polar Orbiting Environmental Satellite. There is the potential discovery of life on ancient Mars. Behind these opportunities is the national challenge to do more with fewer resources. The policy challenges all federal agencies to balance the National budgeL

The policy directs privatization or commercialization of the space communication operations by year 2005 and directs the purchase of space goods and services from the commercial sector. Thus, acquisition authorities will check new investments and acquisitions for conformance with this policy.

National Space Architecture

The National Space Policy also directs DoD, NASA, and NOAA to examine the feasibility y of consolidating ground facilities and data communications systems. In response, the Satellite Operations Architecture Development Team (ADT) is developing a set of candidate designs for satellite control, From these designs the Joint Space Management Board (JSMB) will select a single design. It will serve as a guide for future technology investments and system acquisition planning in the 2010 to 2015 period. How the authorities will compare new investments and acquisitions with the guidelines and what criteria they will use is *yet* to be determined.

NASA[2]

NASA faces a very constrained budget and must concentrate investments in science and technology infrastructure. This focus is necessary for the agency to fulfill its mandate to be a leading edge science and technology engine. Supporting elements provide operations services that enable and facilitate research and development in space science and technology. An effective operations infrastructure is critical to the accomplishment of NASA objectives in space science and technology development, and its capabilities must match the projected growth in information generation of future missions. Therefore, to maximize investment in science and technology, NASA must substantially improve information availability, while reducing operations costs, and continuing to improve the quality of its products.

NASA formed enterprises to carry out Mission to Planet Earth, Space Science, Human Exploration and Development of Space, and Aeronautics. The strategic plans of three of these enterprises, as listed below, drive space operations.

Through 2002, Mission to Planet Earth will deploy the Tropical Rainfall Measuring Mission and the first series of the Earth Observing System missions, including Landsat 7. This period will also see the first launches of two classes of satellites. First is the Earth System Science Pathfinder class that are small satellite missions for new science. Second is New Millennium missions for development of the technology of Earth science instruments.

The goals of Human Exploration and Development of Space are:

(1) increase human knowledge of nature's processes using the space environment
(2) explore and settle the solar system,
(3) achieve routine space travel, and
(4) enrich life on Earth through people living and working in space.

The goals of Space Science Enterprise for the coming decade are

(1) complete the initial capability to observe across the electromagnetic spectrum,
(2) survey cosmic rays and interstellar gas as samples of extra-solar matter.
(3) carry out basic new tests of gravitational theory,
(4) develop the means to understand solar variability and its effects on Earth,
(5) complete initial exploration of the inner and outer frontiers of the heliosphere,
(6) complete solar system reconnaissance from the Sun to Pluto,
(7) survey and begin surface exploration of the most fascinating and accessible planetary bodies,
(8) begin a comprehensive search for planets and planetary formation around other stars,
(9) complete the inventory of near-Earth objects down to a l-kilometer diameter,
(10) determine the abundance and distribution of biogenic compounds conducive to the origin of life, and
(11) identify locations in the solar system where conditions conducive to life have existed.

Also very important, the character of the mission set is changing from a few large missions to many small missions. So the scale of missions that the System must accommodate range from single instrument 500 kg. spacecraft to the International Space Station and large facility instruments like the Space Telescope.

Moreover, the enterprises may fulfill their operations needs from sources other than the Space operations Management Office.

NASA is converting to a full cost accounting procedure to ensure that costs are equitably accounted to the true customers of a service. How this will effect the demand for space operations services is unknown.

Industry

In response to the National Space Policy, to off-set lower funding by reducing government infrastructure, and to develop new industries, NASA seeks to increase industrial participation in space operations. This involves developing new commercial services, procuring more commercial flight items, and developing applicable technology. This environment encourages industry assessment of what the NASA space operations infrastructure should be, encourages procurement of end-item capabilities, purchase of existing commercial space services, and the organization of industry-government partnerships for technology development. The NASA-industry interface will continue to evolve creating a dynamic working environment and relationship with industry.

The System Today

The NASA Space Operation System consists of all the functions, services, tools, physical elements, and people that NASA uses to do space mission operations. The designers of the System of today optimized the characteristics and performance for individual missions in the deep space, human exploration, near Earth, and suborbital mission domains. Some cases optimized over a mission domain, but only to a limited extent. Consequently, there is significant duplication of functions and insufficient interoperability among the network.. and mission control centers in the System,

For example, the Deep Space Network optimized for extreme receiving sensitivity, high power transmission, and reliability. The human exploration domain optimized for flexibility across a large number of diverse users, but human safety and system reliability properly dominated all aspects. The Space Network part of the Low Earth Orbiter Network optimized to support a large number of small, low bandwidth (< 100 Kbps.) spacecraft, and a few large, high data rate (<300 Mbps.) spacecraft

Generally, each of the mission control centers uses different planning, scheduling, telemetry processing, command processing, and data archiving tools. Yet, the basic functions for these services at each center are the same. Only at the parameter value, specific data element level, and data content level are there differences that are unique to the mission domains.

In all of these optimization, development and operating costs were a limitation, but they were not the dominant factor. Consequently, the current System is more expensive to operate and maintain than the economic environment will support. The design of the System needs to change based on new principles and providing new characteristics.

Vision[3]

NASA conducts space operations through an infrastructure created in partnerships with industry, academia, and other agencies. This infrastructure, the NASA Space Operations System, provides data acquisition, space vehicle control, mission services, and products with the same ease and reliability as acquiring services and products from a public utility. The System is essentially transparent to the user and the user can acquire reliable service with minimal knowledge about the details of the system, The System is scaleable. It adapts to match the requirements of future missions. The partnership encourages and enhances the competitiveness of the national space operations industry.

System Characteristics

To meet the increased service demand and yet reduce the cost of operations, the NASA Space Operations System must change. It must provide the services to the users without requiring custom design and development for nearly every new mission or set of missions. There are 8 characteristics that are important to meeting the need.

Public Utility

The System must provide data acquisition, space vehicle control, mission operation services, and products with the same ease and reliability as acquiring services and products from a public utility. ordering these services should be as simple as ordering telephone service or buying an airline ticket. During the design phase of a mission the designers should merely look-up the needed services in a catalog and specify which the mission needs as a function of the mission phase. This is, of course, done from their workstation and they receive nearly immediate confirmation of the availability or possible scheduling constraints.

Invisible System

The space mission designer should not have to worry about or even know the details of the System, With increasingly smaller design and operations staffs for many of the missions, the staffs can not afford spending months in learning, analysis, negotiation, and testing of services. An analogy is the current cellular telephone user. After the initial purchase of the service, they simply access the service through a handy terminal. They care little about which protocol the service uses to hand-off their call from one cell to another or even that the system hands off their call. The system is invisible to them. Similarly the NASA Space Operation system should be invisible to the user and the user can acquire reliable service with minimal knowledge about the details of the system.

Scaleable System

The mission set that the System serves is very volatile, changing almost weekly. Variations in budgets, missed deliveries, technical problems, new science discoveries, political considerations, and other factors cause frequent changes in the content, schedule, and technical details of the mission set. It is important that the System be scaleable and able to adapt to the demand so that there is neither excessive capacity nor excessive under-capacity. Either condition causes increased costs and inefficiencies.

In the Deep Space Network wc have found that an under-capacity of 10 to 15% of demand is manageable. But under-capacity of 40 or 50% causes excessive costs for customer and provider alike. These are as extraordinary planning, extensive negotiations, and lost services. Thus, the System must be scaleable. It must readily adapt to match the capacity and performance demands of the missions.

Part of the scaleabilit y can come from negotiated international and commercial agreements for service at set tariffs. Then, the asset controllers could simply buy and schedule the needed services in a manner as users of today buy and schedule bandwidth on a public communication network.

Functional Interconnection

Today, there arc physical connections among the NASA networks and control centers. However, fcw of the connections are functionally coordinated. If, for example, a principal investigator or mission controller needs to establish links with a near Earth spacecraft using the Low Earth Orbiter Network and the Deep Space Network, they must coordinate the efforts of at least three and in some cases four organizations. Rather, the principal investigator or mission controller should be able to establish such links from a single workstation using standardized service request formats and procedures.

To achieve this type of operation, appropriate elements in the NASA Space Operations System should functionally interconnect; that is, be functionally integrated (not just physically networked). This means that functions that are physically at different facilities interconnect in a way that the composite of the functions appears as a single service interface to the user. Service interface means the interface that the user sees for both the request for services and the delivery of data as a result of service execution.

Standard Services

The use of standard services enables interoperability such that any customer, that is principal investigator or mission controller, can obtain different types of services from multiple operations centers.

Let's assume that a principal investigator has correlated instruments on three spacecraft one in near Earth orbit, one on the International Space Station, and another on a highly elliptical orbiter. He needs to acquire correlated telemetry from the instruments including the ephemerides of the instruments. Today he would have to combine data from three different NASA Centers in three formats.

By standards and the interconnection of functions discussed above, the System should function in the following way. The investigator requests the telemetry data and ephemerides in one request, using one format. The one request specifies the three spacecraft, the time interval desired, the telemetry parameters, the precision, the accuracy, and the output format (all as described in a catalog). Then, the System responds by automatically acquiring the telemetry and metric tracking data from the spacecraft, the International Space Station, and the Deep Space Network. It formats the telemetry data, computes the respective orbits, computes the ephemerides, and transmits the data to the investigator's data base. The System does all of this without further intervention by any manager, operator, or clerk.

To achieve this response, a significant number of functions and external and internal interfaces of the System must be standardized. Some examples of these arc:

1. Asset scheduling,
2. Telemetry formats between the spacecraft and ground receiving stations,
3. Telemetry formats after the data is acquired by the networks,
4. Radio metric data formats,
5. Radio metric data filtering algorithms,
6. Data storage formats, and
7. Data product formats,

The networks above are the Low Earth Orbiter Network, the Deep Space Network, and whatever form of commercially operated networks provide service to NASA space mission operations in the 2010 era.

Object-Oriented

There are many ways in which the various functions that make up the services can be implemented. However, the System should implement the various functions using an object-oriented approach! It should instantiate each service through replication of objects such that the characteristics of each subsystem can be "transcribe" to other subsystems among the networks and control centers within the constraints of physicat assets. Examples include planning services, scheduling, telemetry services, and data distribution.

This approach has several advantages. First, it allows necessary replication of similar functions at severat physical locations conveniently and at low cost. Second, it promotes standardization. Third, it promotes more uniformity in the quality of the services; and fourth, it reduces the cost of customizing services for the few missions that require unique capabilities.

Preservation of Unique Mission Categories

While a high degree of standardization of functions is mandatory to achieve the economies needed, the unique identities of functions associated with the four mission domains is necessary too. For example, a planning function or a command verification function must account for the difference in round-trip communication delay between a near Earth orbiter and a Jupiter orbiter (milliseconds versus hours). Also, when selecting the principal locations for various functions, the location should make the most sense considering cost, efficiency, and available skill base.

Self- alibrating, Self-testing, and Self-healing.

Modern commercial communication networks have automatic fault detection and correction features. These operate so rapidly that users frequently are not aware when a fault occurs and the system corrects it. Only to a limited extent are these features available in the NASA Space Operation System. In the tracking networks in particular, it is common practice to calibrate and test aground station and associated equipment just before each spacecraft tracking session, This was necessary when the technology for space tracking stations was primitive. Now however, this mode is unnecessary and inefficient. The System must be self-calibrating, self-testing, and self-healing.

Conclusions

The international and national environment for the conduct of space missions has been changing significantly over the last several years. The changes require that the NASA Space Operations System substantially increase its productivity and reduce the cost of providing space operations services. Eight principles and characteristics applied to the design of the System would help meet the challenge. Appear as a public utility. Be invisible. Be scaleable. Provide functional interconnection. Provide standard services. Be object oriented. Preserve unique mission categories. Be self-calibrated, self-testing, and self-healing.

References

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